Research Note 81-18

CHRONICLE OF THE EVOLUTION AND POTENTIAL OF THE NETMAN MODEL

Arthur I. Siegel and J. Jay Wolf
Applied Psychological Services

TRAINING RESEARCH LABORATORY

U. S. Army
Research Institute for the Behavioral and Social Sciences

May 1981

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Research Note 81-18	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Chronicle of the Evolution and Potential of the NETMAN Model		5. TYPE OF REPORT & PERIOD COVERED Research Note June '80-May '81
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Arthur I. Siegel J. Jay Wolf		8. CONTRACT OR GRANT NUMBER(s) MDA903-78-C-2013
9. PERFORMING ORGANIZATION NAME AND ADDRESS Applied Psychological Services, Inc. Science Center Wayne, PA 19087		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2Q162717A790
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Research Institute for the Behavioral and Social Sciences 5001 Eisenhower Ave., Alexandria, VA 22333		12. REPORT DATE May 1981
		13. NUMBER OF PAGES 60 + viii
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computer Simulation	System Analysis	Operator Analysis
Exercise Management	Readiness	Human Factors
Exercise Control	NETMAN	Manning
Human Performance Reliability	Exercise Evaluation	System Load

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The NETMAN computer simulation model, its development, evolution, and results from its sensitivity and validity testing and application are chronicled. NETMAN simulates message processing in computer-based military field exercise control systems. In order to present NETMAN in historical perspective, its genealogy and its parent model (MANMOD) are described. Emphasis, however, is given to the efforts devoted to NETMAN during the past three years of research, which this report also summarizes.

The logic and structure of NETMAN are presented, and the model's strengths and weakness are assessed in a critical evaluation of its current status as a tool.

Chronicle of the Evolution and Potential of the NETMAN Model

Arthur I. Siegel
J. Jay Wolf

prepared for

U.S. Army Research Institute for the Behavioral and Social Sciences
Alexandria, Virginia 22333

by

Applied Psychological Services, Inc.
Science Center
Wayne, Pennsylvania 19087

under

Contract MDA903-78-C-2013

May 1981

EXECUTIVE SUMMARY

An overview is presented of the past efforts, extending over more than five years, relative to the NETMAN computer simulation model. NETMAN's goal is to allow analysis of military field exercise control systems through digital simulation techniques. The efforts include design of the simulation model itself, extensive sensitivity tests, model enhancements, validity testing against outside criterion data, and application of the model to a new field exercise control system concept.

The NETMAN model is structured to simulate the message handling aspects of:

(1) field exercise data collection and message coding by referees;

(2) message transmission by radio operators;

(3) message entry into and processing by a control computer including decoding and data base update; and

(4) receipt of the decoded message by a controller.

The tasks performed at each level (plus delays) are simulated stochastically and results are generated in terms of message processing effectiveness.

Objectives

The primary purpose of this report is to summarize the past and recent efforts using the NETMAN and its predecessor model (MANMOD) so that an objective evaluation can be made for future action and/or utilization. This purpose is accomplished by overviews of the models and summaries of all efforts and results achieved. References to original reports are presented in the bibliography. This report is oriented primarily for those who are not concerned with the specific programmatic or functional details of the model but who want an assessment of its value and utility or are interested in its potential for future application.

Scope of Report

This report includes several summary chapters on the NETMAN model's background:

- Chapter I presents the objectives of NETMAN, a chronological summary of its predecessor model (MANMOD), and a similar historical summary of NETMAN
- Chapter II offers an overview of the logical structure and operation of both models.

These are followed by overview chapters which review recent efforts:

- Chapter III reports on sensitivity and validation tests, beginning in 1977, conducted on NETMAN
- Chapter IV introduces a new concept for a more automated field exercise management system than is presently operational called Exercise Monitoring, Assessment, and Reporting System (EMARS). This chapter also reports on the effort in which NETMAN was employed to simulate the EMARS system.

Last, the future of NETMAN is evaluated:

- Chapter V summarizes the experience to date on the applicability of NETMAN. Its potential and its limitations are discussed and conclusions and recommendations are presented.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

BACKGROUND

Objectives of NETMAN

The NETMAN computer simulation model was developed to provide a technique for economical, yet thorough, investigation of alternatives in the design of military field exercise control systems. NETMAN permits its users to evaluate the relative impact of such factors as personnel distribution, system configuration, training, and workload. In general, field exercise management systems perform one or more of the following functions:

- control or management of field exercises
- tracking of exercise progress
- calculation of scores for assessment of combat performance and proficiency
- display of combat and unit performance status
- preparation of performance readiness reports
- support of after action reviews

Figure 1-1 presents the basic elements of a total Army field exercise management system. The figure is intentionally shown with such generality as to be useful in describing the features of essentially any monitored Army field exercise. Figure 1-1 shows as unit "A" the friendly force, whose competence is to be tested, together with their total resources. Their combat opponents (opposing force) are shown as unit "B." The designation, "C," identifies the instrumentation and measurement subsystem. It includes the totality of all resources deployed on the exercise range or elsewhere to monitor the exercise and to report the performance of the forces. The components offering the means by which the communications are effected is termed the communications subsystem, "D." The communications subsystem, provides the capability for the instrumentation and measurement subsystem to report its findings for analysis.

The exercise control function ("E"), as its name implies, consists of those personnel who: (1) establish the exercise conditions and the combat objectives, and (2) define the required documentation, procedures, directives, and resources.

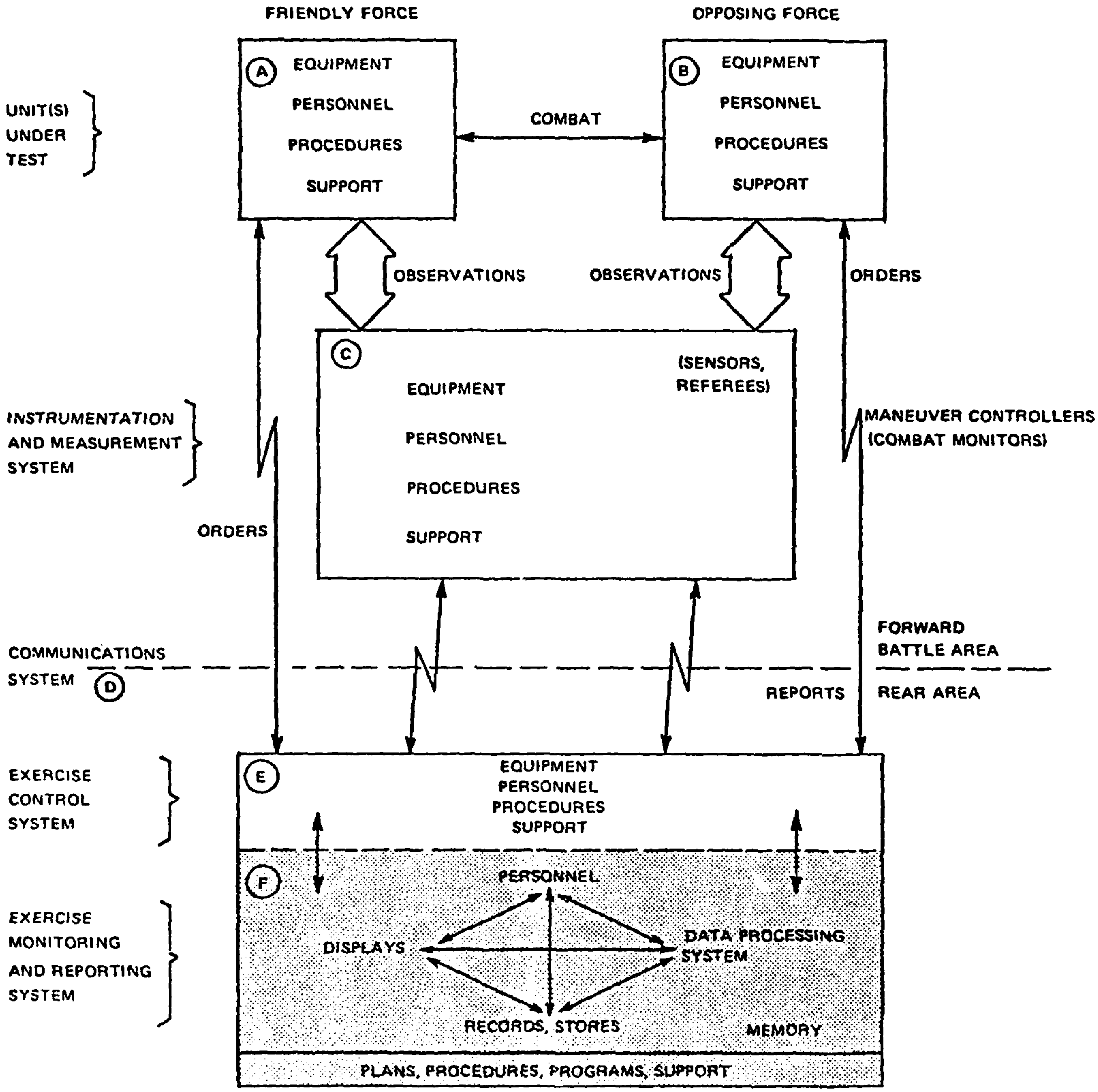


Figure 1-1. Basic elements of an exercise control and management system.

The exercise monitoring and reporting subsystem is designated as "F" in Figure 1-1. This subsystem manipulates data provided as input to determine, display, and report on status and unit performance, and convey the lessons to be learned to the exercise participants at all levels.

Field training exercises serve an important role in the training of military units for the rapid transition from peacetime readiness to wartime effectiveness on the modern, highly lethal, dynamic battlefield. The current manual system[1] for conducting such exercises imposes costly demands on resources during the period necessary to form and train the exercise staff and to plan, conduct, and report on the exercise. In addition, the methods and techniques for maneuver control, casualty and damage assessment, and simulation of combat events are unwieldy and time consuming, degrading the training effectiveness. These aspects serve to encourage the development of new exercise control systems. A model such as NETMAN makes test of such new systems possible while the systems are in the conceptual stage of development.

Based on a general purpose model of information processing systems, NETMAN simulates selected operations (i.e., staff duties, staff functions, and machine functions) as a joint function of the interactions between the exercise data flow, human information processing, and other sources of variance (e.g., personnel characteristics) to produce predictions of overall system performance. On-line inputs to the program permit simulation of candidate configurations that reflect changes in personnel and machine functions (particularly at the man-machine interface), and level of personnel training for comparison of alternatives (i.e., the ability to ask "what if" questions on-line.) Appendix A to this report provides a summary of why, how, and when to use the NETMAN simulation model.

Chronological Summary of NETMAN and Precursor Systems

This section presents a historical perspective of the development, testing, and utilization of two message or communications-oriented man-machine simulation models called MANMOD and NETMAN.

MANMOD Model

Work on a model, started in early 1972, led to the MANMOD program to simulate the details of message processing within the current field exercise control system called TOS.

[1] FM 105-5, Maneuver Control, 31 December 1973.

TOS is an automated, secure information processing system designed to assist military commanders and their staffs at Field Army, Corps, and Division levels in the conduct of tactical operations. The TOS is part of an overall Integrated Battlefield Control System. It serves information collection and dissemination functions--such as transmission of orders, information requests, and practically any information concerning the battlefield situation.

MANMOD simulates the activities within a single communication station in the TOS field army situation. The station is manned by one or more G-3 (operations) officers, and one or more action officers. These men receive messages of various types which are delivered to the station at times unknown in advance of the simulation. Their function is to screen incoming messages, decide on the order in which the messages are to be processed, select the appropriate message form to which they transform the content of each message, and enter the messages into the TOS data bank. The model simulates the acts and behaviors of TOS personnel as they receive, prioritize, code, and enter messages into the TOS computer. The model is completely general and allows for the simulation of personnel of different competency and stress tolerance, along with a variation in message load and content. Output from the model allows statement of personnel error source, time delay, and error type within the processing sequence. The model was designed for standard batch run processing on the CDC 3300 computer.

In the first stage of the development of MANMOD, the model's output was verified through a comparison with independently collected criterion data. Substantial correspondence was indicated between the criterion data and the predictions of MANMOD. Accordingly, initial confidence in the validity of MANMOD was supported. The model, user instructions, and sensitivity testing were presented in Siegel, Wolf, and Leahy (1973).

In a follow-on effort, (Siegel, Wolf, Leahy, Bearde, & Baker, 1973), the model was modified to operate in an interactive time sharing mode, allowing the experimenter to interact in a "conversational" mode with the model and to enter data "on line." This interaction, performed through a computer terminal, greatly increased the ease with which simulations could be performed. Various extensions of the original model were also made at that time.

A variation of MANMOD was developed to allow intermingling of real time experimental data and computer generated simulation data. In this variation, one or more actual system operators process messages

at one level of the TOS system while the computer simulates the rest of the TOS (Leahy, Lautman, Bearde, & Siegel, 1974).

In 1974, (Leahy, Lautman, Bearde, & Siegel, 1974) the MANMOD was adapted for the Univac 1108 computer. The system-specific aspects of FORTRAN were removed, and the logic was modified and the output extended. These increased the realism of the simulation. In 1975, the MANMOD was also modified to exchange data with two other Army computer models (CASE and SAMTOS) in such a way as to maximize the strong points of each of the models. Other computer simulation models (CASE and SAMTOS) approach the simulation in different ways and possess different objectives from the MANMOD. The MANMOD allows for the study of the effects of varying operator and manning considerations on message processing effectiveness. The CASE and the SAMTOS models are more concerned with equipment functions with (more or less) constant human operators in the loop.

During the course of the integration effort, a number of logic changes (largely concerned with the simulation of error message processing) were introduced into the logic of the MANMOD. The modifications were tested for sensitivity and reasonableness of effect on model output. The modifications were found to be acceptable from the point of view of both of these criteria. It was concluded that the body of results on hand supported contentions favoring the use of the model for a number of functions relative to system design, training requirements and objectives derivation, personnel requirements, and tradeoffs. A report on the integration (Leahy, Siegel, & Wolf, 1975a) and a user's manual (Leahy, Siegel, & Wolf, 1975b) were prepared.

Additional detail on the chronology of MANMOD's development, enhancement and testing are given in Appendix B.

Chronological Summary - NETMAN Model

In 1975, development began on the NETMAN model itself. Its main function is to enable an understanding of the underlying system aspects of military field exercise control systems. To maximize use of existing modeling concepts, some of the elements included in NETMAN were developed (or adapted) from the previously tested MANMOD. For example, the simulation technique for task-by-task performance evaluation in MANMOD was used substantially intact in the development of NETMAN (Siegel, Leahy, & Wolf, 1977).

Other features from MANMOD integrated into NETMAN include:

- Generation of message queues at the beginning of each simulation iteration
- Simulation of the effects of operator factors, such as speed and precision, on performance
- Stochastic variation (i.e., random combinations of chance events) to increase the generality of the output. This variation requires that a simulation be repeated a number of times and the results averaged in order to produce a stable output
- Automatic listing of inputs and run summaries with various additional outputs available as options.

NETMAN simulates individually each person and each message involved within a semiautomatic technique for evaluating field exercises. Information collection, message preparation, message handling, message processing, and message evaluation are included within the simulation. The personnel involved in a simulation may include up to 27 referees, 27 radio operators, and three controllers interacting in a fixed network of communications lines while sharing time on a central computer.

In addition to an overall measure of performance, the NETMAN provides four component measures on-line and detailed printouts are made available off-line. The detailed message processing output shows the details of the results of the simulation of each task in the processing of messages.

An hourly summary is provided which presents a consolidation of the results of each simulated hour's work across all iterations and includes items such as: number of messages completed, time spent working, end of hour stress level, performance and aspiration, time spent performing various processes, and average time per message.

A simulation run summary, produced after N iterations of the exercise, includes manpower utilization, message processing times, overall effectiveness indicators, and workload summary information.

A full description of NETMAN is contained in Siegel, Leahy, & Wolf (1977) together with a discussion of model utilization, program flow charts, subroutine definitions, user input-output formats, and task analyses.

Initial NETMAN Sensitivity Tests

The 1977 report also described the methods and results of a set of sensitivity tests of the model. These assessed the rationality and sensitivity of the NETMAN model to input variation. While these tests provided no information relative to the predictive validity of the model, the results allowed initial evaluation of the model from the point of view of the reasonableness of its output. Within the tests, four input variables were manipulated (operator speed, operator precision, message frequency, and message length). The results indicated that:

> On the general level, the sensitivity tests indicated reasonable model output directional response to input variation. However, while sensitivity tests results generally supported the rationality of the results, some problem areas were evidenced. The principal problem involved an indication of excessive queuing time because of a logic error relative to the time synchrony of queuing aspects relative to the simulated computer. This error, naturally also exerted effects on the various individual effectiveness indices. Subsequent to the initial sensitivity test runs, this logic was corrected and a more satisfactory set of results were obtained.
>
> ...the results of the sensitivity tests suggest that the data obtained from NETMAN are directionally logical and that the output is sensitive to input variation. To this extent, a workable model can be said to have been achieved (Siegel, Leahy, & Wolf, 1977).

In 1977, a three year program into NETMAN enhancements, testing, utilization, and evaluation was initiated. Initially, the model was the subject of both sensitivity and validation testing. A series of 60 computer runs enabled statistical test of the effects of a variety of personnel and workload variables, manpower configurations, and task variables. The results were found to be reasonable and appropriate; the most influential variables were operator speed, operator precision, and network configuration. The psychological factors (stress, aspiration level) exerted a much less powerful effect on output. The testing and validity analysis is

summarized in Chapter 3 of this report and is described in full in Siegel, Leahy, & Wolf (1979).

<u>Reports</u>

Appendix C contains a table which lists the technical reports which have resulted from the efforts associated with the two models. In addition to the title, author(s), and date of each report, Appendix C also shows the task and number of men simulated in each application.

CHAPTER 2

OVERVIEW OF STRUCTURE OF MANMOD AND OF NETMAN

Chapter 2 contains an overview of the structure and operation of both the MANMOD and the NETMAN models. The presentation begins with a comparison of differences and a summary of common features, followed by a brief review of the logic of the models themselves.

Capability Comparison

Both the MANMOD and NETMAN models, implemented in the form of FORTRAN IV computer programs, keep track of each message processed in the simulated system. They simulate the acts and behaviors of operations personnel as they receive, prioritize, code, and enter these messages into the system. The models are general in that they allow for the simulation of personnel of different competencies and stress tolerances, along with a variation in message load and content.

These models combine the effects of such features as message generation and queuing, detailed message processing procedure, error rates, and personnel characteristics, along with stochastic variations to yield predictions of system performance. The basic nature of both models is stochastic and, as a result, a number of repetitions is required to produce a stable result. Repetitions of a simulation with the same set of input variable conditions are called a run. At the conclusion of a run, the run summary (integrating results of various repetitions) is produced.

Along with the simulation of message processing by operators, the models include the simulation of the computer embedded in the processing system. Global information about both of the message processing models is given in Table 2-1. Both models handle multiple message types and varying message priorities.

MANMOD Model Overview

The MANMOD model combines the effects of such features as message queuing, detailed message processing procedure, error rates, and personnel characteristics, along with stochastic variations to yield predictions of system performance. Parameters which may be varied to study their impact on system performance include:

Table 2-1

Description of Message Handling Models

System Simulated	Tactical Operational System	Military Exercise Control/ Evaluation System
Program Name	MANMOD	NETMAN
Maximum Number of Men Simulated	6	57
Types of Personnel	2	4
Major Input Parameters	Shift Length Number of Personnel Error Rates Operator Characteristics Speed Precision Aspiration Stress Message Characteristics	Shift Length Number of Personnel Error Rates Operator Characteristics Speed Precision Aspiration Stress Message Characteristics Networks
Major Output	System Effectiveness Time Worked Operator Stress, Aspiration Message Processing Statistics Errors	System Effectiveness Time Worked Operator Stress, Aspiration Message Processing Statistics
Development Initiated	1972	1975
Programming Language	FORTRAN IV	FORTRAN IV

- hours per shift
- number of action officers
- number of input-output device operators
- operator fatigue
- error rates (per hour, per type of effort, per type of message)
- personnel characteristics (speed, precision, aspiration, and stress threshold)
- message arrival frequency
- message workload
- message type mix
- message length
- message handling procedure

There are up to four sequences of task elements provided to represent the tasks executed by an operator in performing his duties. Each sequence has a capacity of up to 20 task elements. The model handles up to 6 men of 2 types (any combination of Action Officers and Input-Output Device [UIOD] operators), 4 types of operator errors, 7 types of message, 5 message priority classifications, and a shift length of up to 12 hours.

One class of simulated messages is "generated" by the MANMOD at random times. The other class involves situation reports which are assumed to arrive only during the last quarter of a given hour. To process both classes of message, the performance of one or more UIOD operators is simulated. Working from the queue of message forms prepared by the officers, the UIOD operators enter each message into the Tactical Operations System (TOS) using a keyboard and CRT edit/verify device. The purpose of the model is to simulate these personnel on an hour-by-hour basis over a single work shift. MANMOD treats the above general task assignment to operators and the sequencing thereof as soft, i.e., since they are controlled by input data, they may be readily changed.

Structure of the MANMOD

Figure 2-1, taken from Siegel, Wolf, and Leahy (1973) shows the subroutines and their interrelation with MANMOD's main processing flow. Following data read-in, there is an optional recording of the input data. Conditions are then reset (circle b) for the start of simulation for a new TOS shift. The backlog subroutine (BAKLOG) generates data representing messages in the Action Officer's "in-box" at the start of each iteration. At circle c, following reset of counters and registers for

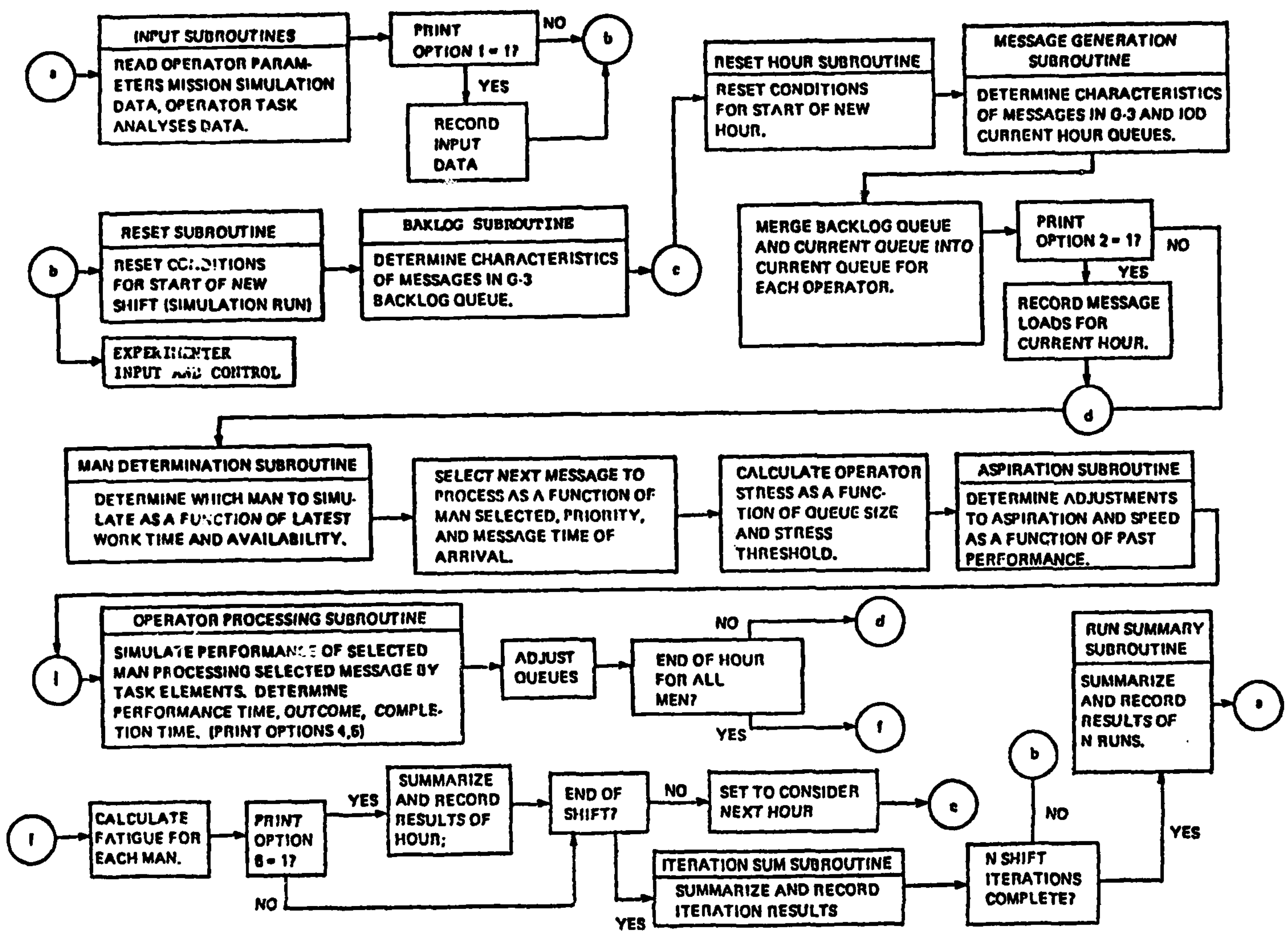


Figure 2-1. Summary of initial MANMOD flow logics (from Siegel, Wolf, & Leahy, 1973).

record keeping of hourly results, the message generation subroutine develops data representing messages which will arrive during the coming hour. These are merged with the backlog in order by time of arrival, and the contents of this hourly message queue are optionally recorded. At circle d, the processing of each message in turn by a single operator (either G-3, Action Officer, or UIOD operator) begins. The Man Determination Subroutine selects the appropriate man to simulate next, and determines the next available appropriate message for this selected man to process. The operator stress and aspiration conditions applicable to that operator message situation are calculated next. At this point (circle j), all data are available for the detailed task element-by-task element simulation for the message and operator selected. This is accomplished by the Operator Processing Subroutine which manipulates mission task analysis data. During this subroutine, the detailed results of the simulation of the performance of each task element, as well as the summary results for this one message, may be optionally recorded for printing.

Following this, queues are adjusted and the cycle goes back to circle d for processing of all messages which can be handled before the next one hour segment is completed. When the end of an hour condition is reached for all men, the results of the hour's simulated activity are optionally printed. The process of simulating in one hour segments is repeated (back to circle c) until the simulation of one iteration of an entire shift is completed. When a shift iteration is finished, the iteration summary subroutine generates summary data over the shift. The process is repeated (back to circle b) for each iteration and after all iterations are completed, the run summary subroutine summarizes and records all the pertinent performance figures to complete a simulation run. Multiple runs are processed sequentially through the entire process by returning to the input subroutines at circle a and processing continues for as many sets of data as are provided as input.

Each computer run of the model represents a simulation of up to 10 hours in duration, in which up to 2000 messages can be processed. In this model, each operator type has its own task analysis.

The end result is the ability to answer questions such as:

- How does system effectiveness vary as a function of message load, operator level of aspiration, message arrival time distribution, or personnel proficiency?

- What is the effect of increasing or decreasing the manning level or personnel proficiency?
- How much stress is on the operators during the performance of the work of each hour?
- What is the error rate for various message types and for various mannings and personnel attributes within each manning?
- How much time is spent, on the average, processing each type of message?

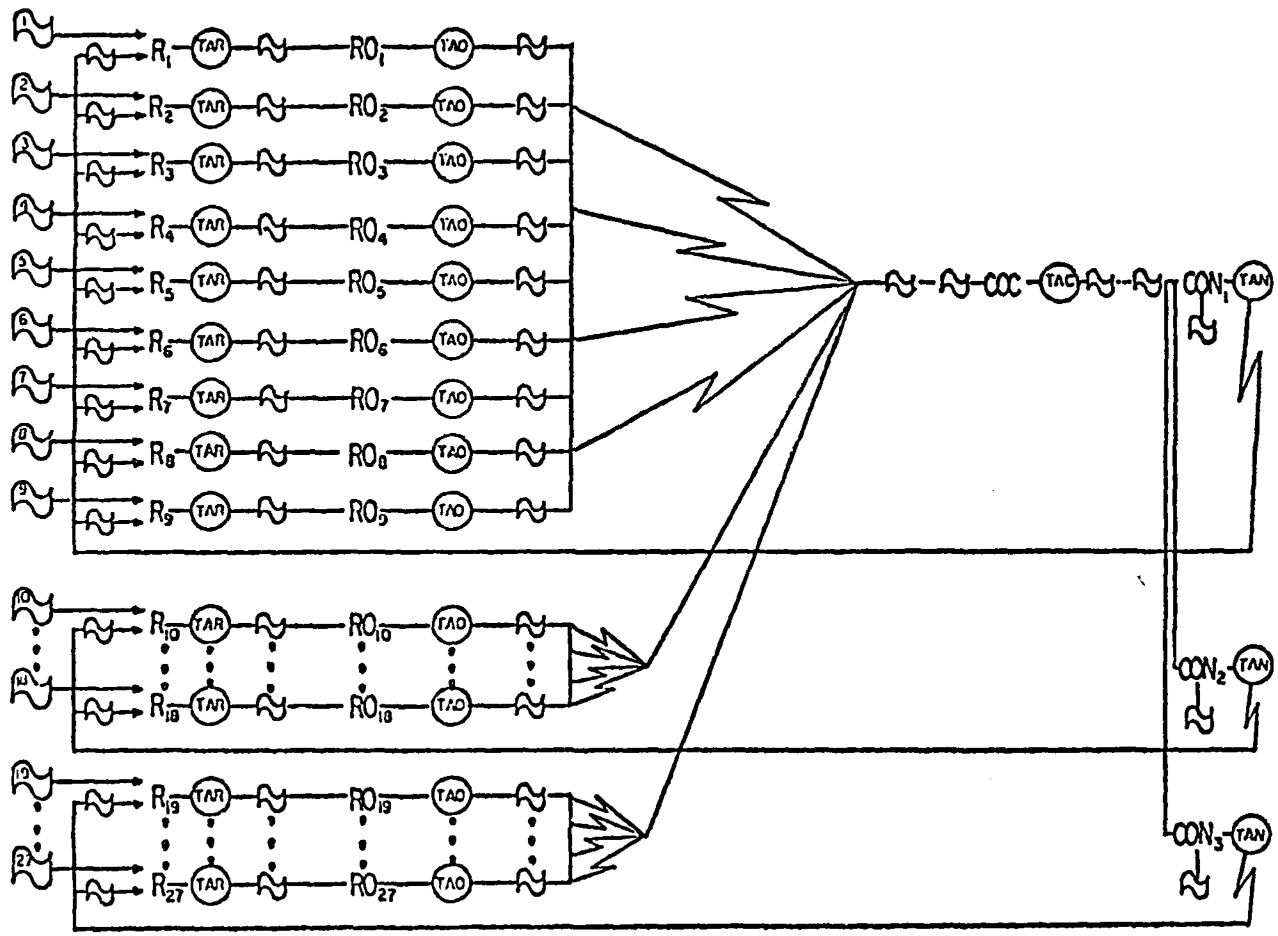
Overview of the NETMAN Model

The NETMAN model was designed to allow simulation of message processing in a system composed of up to three networks. Each network may be composed of up to nine referees, up to nine radio operators, and one controller. One computer is assumed to accommodate the three networks. As such, the model allows simulation and test of the effects on system effectiveness of varying such aspects as: number of referees, number of networks, task procedures, message arrival rate, message length, and operator characteristics.

The results of the simulation are interpretable in terms of a number of formal effectiveness measures (accuracy, thoroughness, responsiveness, completeness) and an overall effectiveness index. Additionally, the results are interpretable in terms of such model results as work time, stress imposed, message processing time, errors, number of messages processed, and fatigue.

Structure of the NETMAN Model

The overall flow of the field exercise data processing situation is configured as a message processing throughput as shown in Figure 2-2. The path of information transmittal is primarily from left to right in the diagram. The far left column, containing flags numbered from 1 to 27, represents available field situation information. Based on this information, his awareness of it, and his interpretation of it, the referees (R_1 to R_{27}) encode messages for transmittal. The procedure followed by the referees in the performance of their duties is detailed in a task analysis (TAR). The resulting messages are delivered to radio operators (RO_1 to RO_{27}) who process the messages and pass them to the CCC. The CCC decodes the message, instantly uses the information to update various status tables, and makes the decoded messages sequentially available to the field exercise controller (CON). The procedure followed by the computer is represented by (TAC) while the controller's tasks are shown by



TAR = TASK ANALYSIS, REFEREE; TAO = TASK ANALYSIS, RADIO OPERATOR; TAC = TASK ANALYSIS, COMPUTER
TAN = TASK ANALYSIS, CONTROLLER

Figure 2-2. Schematic of message processing flow.

TAN. As part of his task, the controller may communicate verbally with the referees. This communication, as simulated by NETMAN, is unidirectional and does not include interactive aspects.

The respresentation of this situation, as simulated in the NETMAN model, is shown in Figure 2-3. A full description of the detailed internal logic of the model and the data flow within the model is presented in Leahy, Siegel, and Wolf (1980).

As shown in Figure 2-3, processing proceeds within the model in segments. Each segment is completed before the succeeding segment is activated. For example, in block 2.0 all of the messages which will be available to be processed during a simulation are generated before simulation begins. After generation of the messages, control passes to subroutine REFRE. After completion of the processing of one message for each referee, subroutine RADOP becomes operational. In RADOP each radio operator processes one message. After each radio operator is finished, the messages are sorted for proper arrival time to the computer and then sent to subroutine CCC which processes each message. After the computer has completed each message, control passes to subroutine CONTR. CONTR simulates the processing of the messages by the controllers. Note that the processing of each message is not performed in true time synchrony with the simulated system. Instead, each message is tagged with simulation processing times and delay times, which occurred during the processing. Since each message is independently processed, time synchrony is not needed and does not affect the fidelity of the output.

NETMAN's limits are shown in Table 2-2. Some of these limits can be changed by the user. However, since such changes require a large number of changes throughout the program, these changes should not be considered trivial. Other limits, such as the range of values for operator speed or operator precision, are based on experience in the use of NETMAN. The use of values outside these limits violates the validated and, thereby, trustworthy use of the model. Violation of some of these limits (e.g., use of operator precision values in excess of 1.1) may result in a perpetual loop within a simulation.

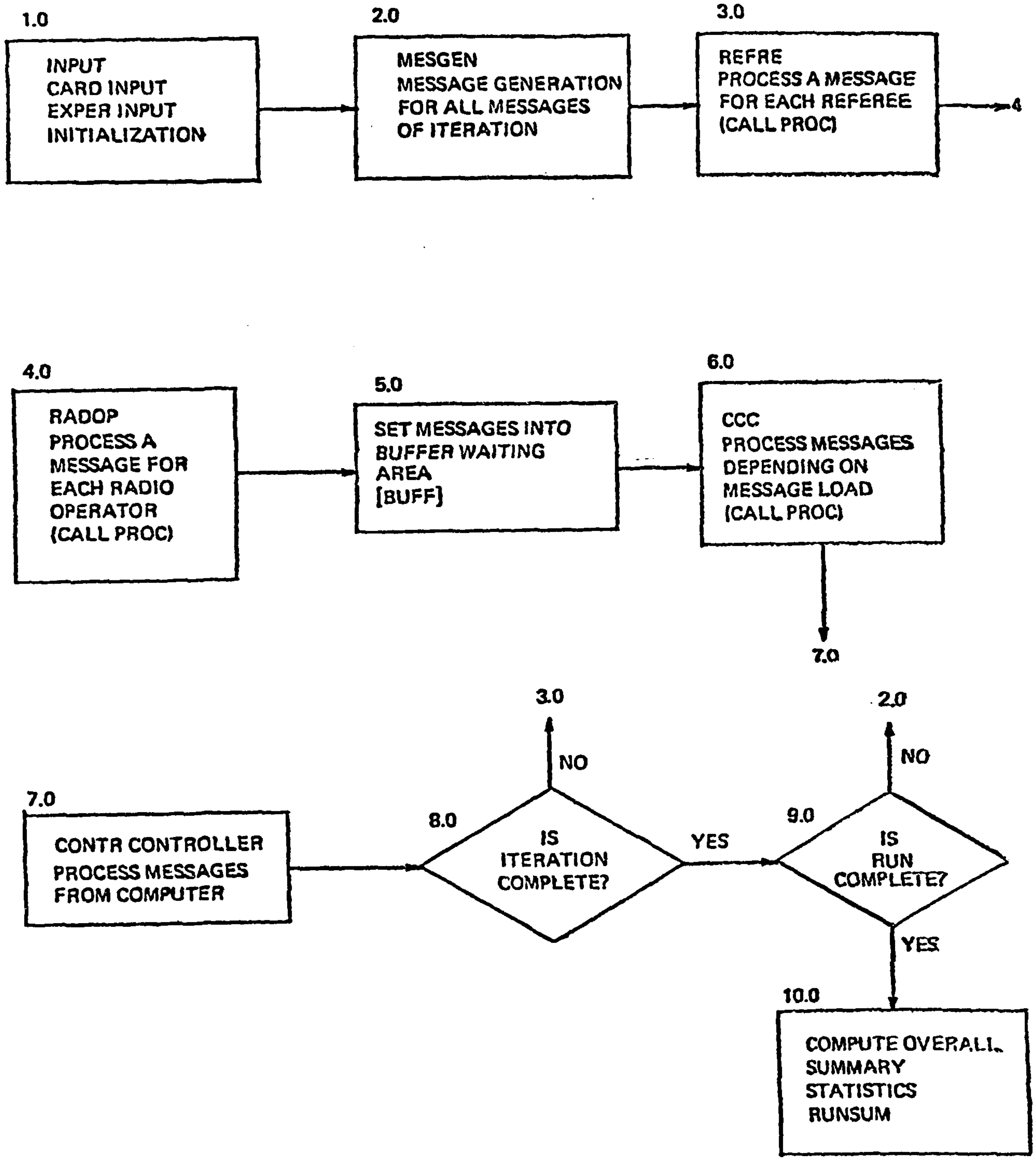


Figure 2-3. Overall structure of NETMAN

Table 2-2

Allowable Range for Variables in NETMAN Model

Function	Lower Limit	Upper Limit
Number of hours	1.0	10.0
Number of network levels	4.0	4.0
Number of task elements in each task analysis	1.0	20.0
Number of message types	1.0	7.0
Number of task analyses	1.0	20.0
Number of networks	1.0	3.0
Number of time segments on which counts can be maintained	-	19.0
Number of referee/radio operator teams per controller	1.0	9.0
Operator speed	0.5	1.5
Operator precision	0.9	1.1
Operator stress threshold	2.0	9.0
Operator level of aspiration	0.5	1.0
Days worked	1.0	10.0

CHAPTER 3

SENSITIVITY AND VALIDATION TESTING

Independent Review Panel

After its initial development, the NETMAN model was the subject of sensitivity test, enhancement, and validation.

Before proceeding with the NETMAN sensitivity tests and validation, an independent review of the model was sought. A review panel of independent personnel, expert in various areas of digital modeling and related fields, was brought together. The panel was composed of persons from university, governmental, and consulting organizations. Disciplines represented on the panel were computer programming, mathematics, systems analysis, simulation, modeling, and operations research. The panel made suggestions relative to: model improvement, additional features to be added, features which should be deleted, features which may yield misimpressions, errors in the work, and attributes which are useful. Particularly important were suggestions relative to improvements concerning documentation, sensitivity test considerations, and validation.

The panel found the model to be highly portable, being written in FORTRAN IV with almost no machine specific aspects. (The exception is the random number generator; such routines are usually uniquely developed for each computer system.) The computer program was held to follow the rules of structured programming. Each major function in the program is separated into its own subroutine. This allows program changes to be made relatively quickly. The subroutines were said to be well organized and the interfaces between subroutines to be clearly identified. Internal documentation, including comment cards, was held to be adequate. The fixed format input was said to be difficult for the user and substitution of free format input or more identifying information was suggested. The panel also noted that the program was relatively large and that the stress function possessed a discontinuity.

The panel's suggestions for logic changes included the need for entering human parameters for each man individually and for the inclusion of stress, aspiration, and fatigue in the error generation formula. The panel also suggested different fatigue curves for different personnel types since it thought that the referees and the radio operators in the field may fatigue more quickly than controllers.

The panel also recommended that the capability be added for simulating referee mobility, simultaneous referee observation of multiple situations, and referee decision making functions. Originally the referee was simulated only in his message originating aspect.

Fluctuation of level of aspiration due to local effects such as presence of officers and situational variables was indicated by the panel to be an additional desirable feature along with an increase in the simulation duration capability beyond 10 hours.

A list was compiled of the 22 major issues raised during the panel discussion and each of the six panel participants was asked to judge each item on a five point scale. After priorities were assigned by each panel expert to each item, the mean priority was calculated for each item and the mean priority ratings were ranked. The items, the ranking of the priorities, and an analysis of these 22 issues were included in Applied Psychological Services' report (Siegel, Leahy, & Wolf, 1979) which described this effort.

Three items were tied for first place in priority among the panel suggestions. All of these were accomplished in subsequent work:

User manual enhancement
Programming changes for improved ease of use
Discrepancies between manual and program

The fourth ranked item was utility testing, i.e., the use of the model in such a way as to draw out any problems, limitations, or other unknown program characteristics. This testing was completed in subsequent work (see Chapter 4 of this report).

The next four items were tied in order of priority: norm development, availability of input data, data base development, and abbreviated user mode (input/output data reduction program).

Next, also tied in priority order, were human effects on error rate, inquiry mode for output, and overall processing. The human effects which might be expected to affect error generation are stress, aspiration, and fatigue. The inquiry mode would allow an on-line experimentor to request the specific sets of data or analyses which are relevant for his use. Overall processing refers to the entire throughput and the event oriented sequencing of message handling.

Next ranked was the expanded simulation of referee activity described earlier under logic changes. Some lower priority issues included: graphic output to allow the capability of automatically transforming the model output into bar graphs or line graphs, fatigue curve individualization to allow different decrement curves for different levels of the network as well as different decrements for different operations at the same level of the network, error frequency modification to allow stress to affect the number of errors, catastrophic failure indication to allow consideration of those factors, such as radio failure, which would actually shut down or greatly reduce the effectiveness of the system, and a statistical package interface so as to facilitate data reduction.

Model Preparation for Sensitivity Tests

To facilitate the sensitivity and validation test, a series of fine tuning and readiness-type adjustments was made to the program. These included:

- new control language files to facilitate simulations
- input format expansion to allow entry of the day number for fatigue calculation for each simulated person rather than a single value for all individuals
- input format change to allow input of different values of speed, precision, aspiration, and stress threshold for each person simulated
- message origin identification revision so that all messages originating from the same stimulus message are keyed to that source message
- addition of a new type of task element, random walk task, to better simulate decision tasks. Associated with this a new subroutine, INRAN, was added to control random walk data input
- random number generation correction to prevent its misuse
- variable dimension statement modifications to accommodate larger data arrays for fatigue, speed, precision, aspiration, and stress threshold

- modification to allow simulation of networks which include one referee, one radio operator, and one controller--a case not previously handled by NETMAN
- new files for input, output, and mapping, compiling, and printing elements. These changes facilitated performance of multiple simulation runs
- enhancements to enable the analyst to enter task difficulty and task duration data from the terminal in the interactive mode.

Sensitivity Testing Methods and Results

A series of more than 60 computer runs was completed during 1979 to test the performance of the NETMAN computer model under many different simulated conditions. The effect of these condition changes was then carefully evaluated from the viewpoints of rationality of output, cost, ease of use, and program logic error (Siegel, Leahy, & Wolf, 1979).

The first NETMAN aspect investigated was output stability as a function of number of iterations. In a stochastic computer model (like NETMAN), which can simulate numerous combinations of likely and unlikely events, a number of simulations of the same mission is required in order to arrive at a stable estimate of the output parameter. If an insufficient number of repetitions is used, the output could be sensitive to unlikely occurrences and may be biased. With more repetitions, however, the effect of unlikely events tends to balance out. The more complex the mission simulated, the larger the number of repetitions which are required to produce stable output. A relatively basic mission scenario was used in these tests. The results indicated considerable results stability with a limited number of iterations.

Parameters varied in the major sensitivity tests were: operator speed, operator precision, operator level of aspiration, operator stress threshold, operator fatigue level, number of operator networks, number of referee/radio operator teams per network, undetected error probability, message frequency, message length, transmission delay, and task difficulty. The results which were analyzed from such points of view as reasonableness, meaningfulness, utility, dependability, and reliability generally indicated support for the structural logic and internal validity of the model.

The following quotes from Siegel, Leahy, & Wolf (1979) are representative of the results reported from the sensitivity tests:

(1) As expected, in all cases, improved speed and precision resulted in reduced message processing time.

(2) A strong trend is shown for the percentage time busy to increase as the simulated personnel became slower and less precise.

(3) Statistical significance at the 0.001 level was observed for all three operator types in both the effect of fatigue on performance for the mission time periods and for the hourly (day) periods. This indicates the clear and significant impact of fatigue on operator performance.

(4) A one-way analysis of variance indicated the effect [of undetected error probability] on accuracy to be statistically significant at the 0.001 level.

(5) The expected effect was observed in message processing (messages completed) as a function of number of characters.

(6) ...confirms the anticipated effects of changes in task difficulty on the number of messages per hour. Here, the effect of increased messages processed as tasks become less difficult, is clearly noted for all operators.

Discussion

The major result of the sensitivity tests was confirmation that the NETMAN model produces output which varies in a reasonable manner, with input variation. The most important variables were found to be operator speed, operator precision, and network configuration. The results of the sensitivity tests suggested that the data obtained from NETMAN are directionally logical and that the output is sensitive to input variation. To this extent, a workable model was said to have been achieved.

From the point of view of operator performance analysis, the model was reported to be highly flexible. The analyst may vary operator characteristics and, through task analytic input, the characteristics of the work performed by each operator. Accordingly, a wide variety of "experiments" may be performed by the analyst to determine optimum conditions.

Another result of the sensitivity tests was an evaluation of the ease of use and the cost of use of the NETMAN computer model. In terms of cost of use, the NETMAN program was found to be very efficient since,

in most cases, an extensive number of iterations is not required. The findings relative to ease of use were equally satisfactory. Setup for a new simulation was estimated as not more than 40 man hours, for an experienced analyst. This time involvement was said to depend, to some extent, on the complexity of the system being simulated. Once a simulation has been organized, however, changes and rerunning the simulation were said (Siegel, Leahy, & Wolf, 1979) to be readily accomplished.

NETMAN Model Validation

Following sensitivity testing, a formal validation of the NETMAN model was completed. The purpose of the validation was to compare the model's predictions with the performance of an actual system.

To determine the predictive validity of the NETMAN model, the Marine Corps' Tactical Warfare Simulation, Evaluation, and Analysis System (TWSEAS) was observed during control of a full battalion field exercise. Field observers, assigned to troop units, made measurements of message processing time and frequency. Additional observers collected data in the control center on message handling. In this manner, data were obtained concerning the quality of the operation of the TWSEAS system. Prior to the exercise, the control system personnel involved in the TWSEAS operation during the field exercise were tested to provide personnel operating characteristics for input to the model.

The NETMAN computer model was then run to simulate the TWSEAS performance during the field exercise and the NETMAN-generated data were compared with the criterion data (actual TWSEAS operation).

The actual performance data, called criterion data, were carefully collected to represent as close an approximation as possible to the situation that the model was built to simulate.

As the result of a criterion analysis, eight TWSEAS criterion variables were selected for assessing the validity of NETMAN: thoroughness, responsiveness, total message processing time, referee message processing time, radio operator message processing time, controller message processing time, transmission delay, and overall effectiveness.

Field Exercise

In the field exercise, a full Marine Corps battalion landing team assaulted a beach with armor and mechanized units. The objective of the exercise was to rescue an abducted member of congress. The details of

the exercise included numerous searches, engagements, and movements. The exercise started with an assault on a beach and terminated with the withdrawal of troops back to the ships. The exercise was observed for two successive days (10 hours each day). The withdrawal took place on the third day and was not observed or simulated.

Field Exercise Data Collection

Seven observers were trained and they collected the required TWSEAS performance information. Field exercise data were collected: (1) by observers who traveled with mobile units and collected data concerning referee and radio operator message processing, and (2) at the control van concerning the computer and controller message processing.

Computer Runs Completed

Input data, derived as described in Siegel, Leahy, & Wolf (1979), were entered in the required format for simulation within the NETMAN model. One run was organized to simulate TWSEAS operation during the first day (D-day) of the field exercise and another run was completed to simulate D-day plus one. Ten hours of operation were simulated each day to provide a total of 20 hours of model predictions which could be compared with TWSEAS performance.

Validation Analysis

The agreement between the model's predictions and the TWSEAS performance during the field exercise was examined according to the eight criterion variables.

Thoroughness

Thoroughness within the model is calculated as the number of messages completely processed divided by the number of messages available to be processed in each hour. A tally was made of the number of times that the model's predictions fell within one standard deviation of the field data or within one half standard deviation of the field data. There were 20 comparisons based on 10 hours per day for two days. Out of the twenty comparisons, nineteen of the models hourly predictions fell within .5 standard deviation of the field hourly data. According to the sign test (two tailed), this agreement ratio (19 out of 20) is statistically significant at the .001 level. Since the thoroughness index is fundamentally a measure of network throughput, this finding seems particularly important.

Responsiveness

Responsiveness, within the model, is calculated as the ratio of human message processing time to total message processing time. Total message processing time includes human time plus other time such as delays or waiting time. Model responsiveness predictions fell within one standard deviation of the actual TWSEAS hourly performance data 18 times out of 20. This agreement ratio is indicated to be statically significant by a two tailed sign test at the .001 level of confidence.

Overall Effectiveness

Overall effectiveness, within the model, is calculated as a composite of four individual effectiveness components--thoroughness, accuracy, completeness, and responsiveness.

The model's hourly predictions for overall effectiveness were compared with plus or minus one standard deviation of the TWSEAS criterion in a two tailed sign test. The result was not statistically significant. Ratings of overall system effectiveness by actual controllers were substantially lower than the model's prediction. This lower rating by the controllers may have been due to the presence of equipment and radio transmission difficulties, which were bypassed during the exercise through the use of alternative delivery methods. These difficulties were not simulated in the model. Only messages which are able to pass through the normal TWSEAS channel are considered in the simulation.

Total Message Processing Time

The TWSEAS total message processing time criterion data were compared with the NETMAN output by means of a matched pairs t-test. The resulting t value was .381. With an N of 20, this value is not statistically significant (i.e., the model versus TWSEAS time difference was not significantly different). This finding supports a contention of reasonable correspondence between predicted and actual TWSEAS total message processing time. Since total message processing time is an especially important aspect of the simulation, this finding reinforces arguments favoring the utility of the NETMAN model.

Operator Processing Time

During the field exercise, the time spent working on each message was measured for each individual (of those who were under observation). These data were averaged across operator type to produce mean time per

message per hour for each operator type (referee, radio operator, or controller). The NETMAN produces parallel data. Independent comparisons were performed for referee processing time, radio operator processing time, and controller processing time. In each comparison, the frequency of the NETMAN prediction data falling within plus or minus one standard deviation of the mean of the TWSEAS observational data was determined. In each case, 20 out of 20 of the model's predictions fell within one standard deviation of the TWSEAS criterion. For each position, the two tailed sign test was statistically significant at the .001 level of confidence. This finding indicates considerable agreement between the NETMAN's predictions and the TWSEAS time criterion at all levels of message processing. The agreement between predicted and criterion time is especially important since modeling manipulations of operator time (for example, by varying operator proficiency level or through task revision) can provide important information to system designers concerning the required number of personnel and the required training of personnel in new systems. Such simulations also provide information concerning the workload imposed on personnel, and, therefore, the availability of such personnel for additional responsibilities.

Transmission Delay

Transmission delay in the TWSEAS is represented by the time between a first attempt to transmit a message and the time recorded by the computer as the time of message entry.

Only one overall transmission time output recording is available per simulated day from the NETMAN computer model. This one prediction time was compared with the data for each hour from the TWSEAS criterion. Comparison of the predictions of the NETMAN model with the TWSEAS performance indicated that the model data were within .5 standard deviation of the criterion data in 19 out of the 20 comparisons. This agreement is statistically significant (sign test) at the .001 level.

Integration of Validation Data

Figure 3-1 shows the correspondence between the NETMAN model's predictions and the TWSEAS data in terms of deviation from the TWSEAS data. The "x's" represent the mean model predictions across all hours, while the mean and standard deviation of the horizontal axis represent the mean and standard deviation of all field data points. Two of the predictions agreed almost exactly with the respective criterion--thoroughness and total processing time. Five additional predictions--responsiveness, referee

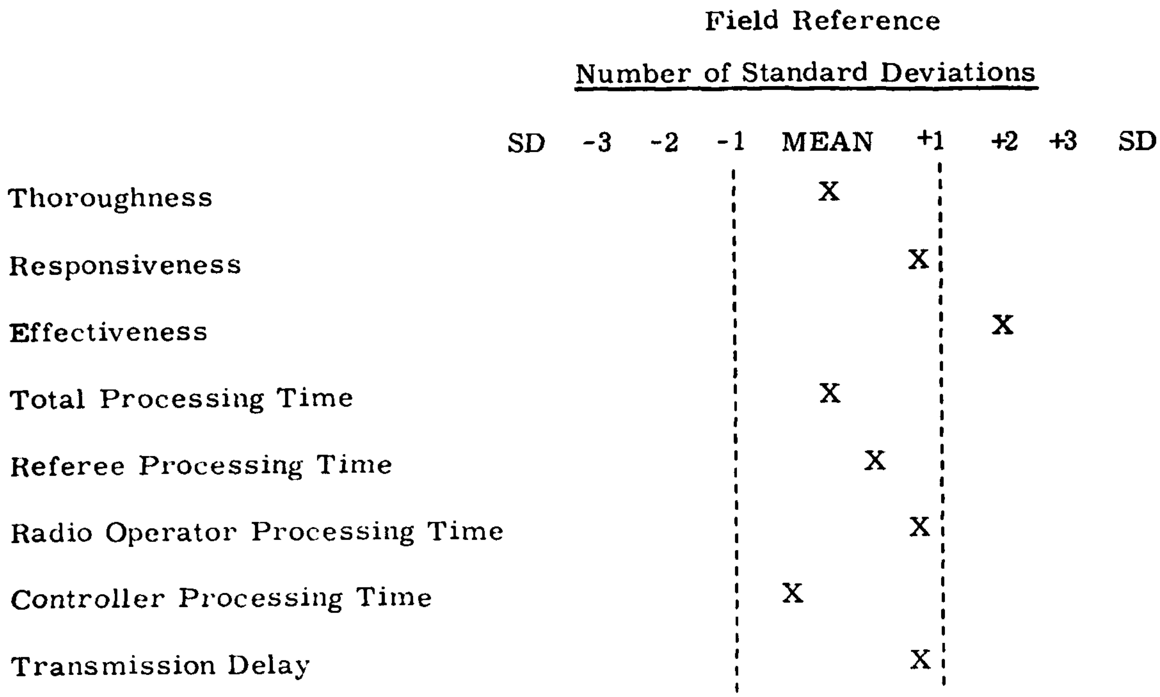


Figure 3-1. Model predictions versus field data.

processing time, radio operator processing time, controller processing time, and transmission delay, were within one standard deviation of the field data. Only one of the indices investigated, overall effectiveness, was more than one standard deviation from the mean of the field data. In this case, the deviation exceeded two standard deviations. As was indicated, there was a lack of correspondence between the TWSEAS overall effectiveness as rated by the controllers and overall effectiveness as measured by the model.

Table 3-1 summarizes the statistics and results of the eight validation analyses. The sign tests were all structured to test the degree of agreement between model and field data. Agreement to within one standard deviation was found in all cases except for overall effectiveness. A t-test was performed to compare model and field total processing time. No statistically significant difference was found between model predictions and TWSEAS data in this case.

Discussion

The results of the validation support contentions favoring the validity of the NETMAN model relative to all but one of the diverse TWSEAS criteria employed. The degree and magnitude of the diverse events involved in field exercises in which a TWSEAS-like system is involved bring out clearly the need for computer models in this area. Where variable occurrences overshadow design variables, the need for improvements is very hard to evaluate. Each field exercise, by its nature, is expensive and provides only a small sample of possible conditions. Within a model, however, the effects of such events can be assessed by combining the effects of many low probability events through stochastic iteration.

It was reported that the criterion quality was believed to be reasonably acceptable, given the limited amount of data, i.e., the number of messages that the referees were able to transmit from the field over the normal TWSEAS system. (The small message sample size represents the primary limitation on the adequacy of the criterion data.)

The measurement of the TWSEAS performance, as performed by the field observers, was believed to be highly reliable. Although no formal independent measures were available, the use of discrete time points and message identifiers when coupled with the training that was administered, allow a high degree of confidence in the reliability of the data. The exercise data, as collected, were highly objective. Discrete, predefined starting and stopping points were identified for time measurements. Subjective evaluations were used only in the case of the controller's overall effectiveness evaluation.

Table 3-1

Summary of Validation Statistics

Variable	Test	Not Significant	Agreement Achieved .001
Thoroughness	Sign		✓ **
Responsiveness	Sign		✓ *
Overall effectiveness	Sign	✓	
Total message processing time	*t*-test	(✓)***	
Referee message processing time	Sign		✓ *
Radio operator message processing time	Sign		✓ *
Controller message processing time	Sign		✓ *
Transmission delay	Sign		✓ **

* Within 1 sigma

** Within .5 sigma

*** The *t*-test as used is a measure of difference while the Sign test as used is a measure of agreement. A non statistically significant difference indicates agreement between the model's prediction and the criterion data.

TWSEAS performance data required little or no transformation, rescaling, preprocessing, or translation in order to be used as criteria.

Sensitivity and Validation Summary

Overall, the results of the sensitivity and validation tests suggested substantial confidence in the NETMAN simulation model.

The conclusions reached by Siegel, Leahy, & Wolf (1979) were:

1. The NETMAN model is adequately sensitive over a wide range of parametric variation.
2. The parametric variation introduced during the sensitivity tests produced results which are reasonable and which possess proper directionality.
3. The results of the validity tests indicate that NETMAN can provide information about exercise control system operation comparable to that available in a field exercise environment such as TWSEAS.
4. Several areas for model improvement are indicated.

NETMAN Enhancements

Following the independent panel review, sensitivity testing, and validation, the combined experience on model strong points and desired enhancements was combined. A series of some 26 potential enhancements was developed. In each case a written description of the purpose and method of the change was prepared. From these, in turn, estimates were made of the cost in time units (scale 1-20) to implement the change and the value (scale 1-10) of the change. The selection of the value rating was determined on the basis of estimates by the model's authors at Applied Psychological Services and by a representative of the Army Research Institute who was familiar with the model. Time estimates were provided by the primary model programmer.

The 26 candidates were rank ordered according to the utility per unit time measure. Those 16 enhancement candidates having the largest measure were selected and implemented. These enhancements included:

1. Reduce total message storage capabilities
2. Provide positive execution statement
3. Increase number of task elements
4. Increase number of tasks allowed

5. Redirect detailed output
6. Increase header clarity
7. Develop user work sheets
8. Individualize effectiveness measures
9. Simulate unexpected interruptions
10. Allow natural form input
11. Revise stress logic
12. Add error checks
13. Develop capability to bypass system levels
14. Modify fatigue calculation
15. Improve time synchrony
16. Expand prompting to user

A revised user's Manual (Leahy, Siegel, & Wolf, 1980) was prepared to document model changes resulting from these changes.

CHAPTER 4

NETMAN APPLICATION TO EMARS

During 1979, Applied Psychological Services developed a conceptualization to two alternative military field exercise management systems. The report describing these system concepts (Siegel, Webb, Wolf, & Wilson, 1980) included summary concepts, block diagrams, subsystem descriptions, personnel requirements, manning requirements, and task requirements for each of the two system concepts.

Technological advances of the last decade provided the impetus for the conceptualization since these advances have provided a capability to revolutionize completely the way in which the combat readiness of ground military units may be evaluated. Moreover, similar changes in technology have changed ground combat per se so as to make new approaches to combat effectiveness and readiness testing imperative. These developments include instrumented training and testing grounds, use of lasers for kill/hit assessment, ruggedized (portable) and miniaturized computational capability, and interactive graphic displays. They offer the potential for simulated battle under conditions of unprecedented realism.

Two different levels of exercise control and monitoring systems were defined. Each meets a different need. The first concept and the one on which the NETMAN application described in this chapter was based represents a modest exercise monitoring, assessment, and reporting system (EMARS). It does not include exercise control. Such a system could be deployed at selected Army division level headquarters areas for use in testing units up to company level.

The EMARS Concept

The EMARS (Siegel, Webb, Wolf, & Wilson, 1980) is conceived as a computer assisted exercise monitoring system. The EMARS can support field exercise administration for exercises up to and including the company level. Its overall functions are to:

- monitor the activities of units during an exercise
- integrate the information required for exercise control
- accept and process field data and information
- generate situational displays

- assess performance and generate objective scores for individual units and combined military units at all tested levels by time period
- support exercises up to four days in duration
- provide multiple hard copy results--maps, records, scores, and referee comments
- be capable of one day readiness between exercises.

Application of NETMAN to EMARS

The EMARS concept provided a "test bed" for evaluating the adaptability or utility of NETMAN for evaluating systems while they are in the conceptual stage of development. Quite obviously, models such as NETMAN, are of maximum utility if they can provide evaluative insight while systems are in the conceptual stage of their developmental cycle.

The EMARS accomodates five persons: personnel/logistics monitor (PER/LOG), operations intelligence monitor (OPS/INT), indirect fire and air space manager (IF/ASM), exercise management and information controller (EMIC), and exercise monitoring officer in charge (EXMOIC). The first three of these possess the responsibility for receiving and assembling information relative to their respective interest areas, coding the information, and entering the information into the data management computer system. The final two EMARS personnel, the EMIC and the EXMOIC, possess decision making responsibility.

Accordingly, the PER/LOG, OPS/INT, and IF/ASM personnel were conceived as analogous to the radio operators in the NETMAN scheme and the EMIC and the EXMOIC were conceived as controllers in the NETMAN scheme.

Referees are not included in the EMARS concept. Rather, information is assumed to arrive at the EMARS through a variety of other sources. Accordingly, the referee representation was not considered relevant to the present simulation.

The capability to bypass a system level during message processing, (item 13, page 32) was utilized during the EMARS simulation. The system level bypass feature was used at the referee level although message generation was simulated.

Accordingly, the EMARS simulation involved three levels:

	NETMAN Model Level		
	RO	Computer	Controller
EMARS Position	PER/LOG OPS/INT	Computer	EXMOIC
	IF/ASM		EMIC

This organization allowed full simulation of the EMARS including receipt of field based information by EMARS' computer personnel, (PER/-LOG, OPS/INT, and IF/ASM), entry of these data by EMARS' personnel into a computer based management system and processing of these data by the computer, and action on the basis of the data by EMARS' decision making personnel (EMIC and EXMOIC).

Stated alternatively, the EMARS' personnel described, their functions and numbers, were defined in NETMAN as two operating networks. In each network there were three levels: (1) PER/LOG, OPS/INT, and IF/ASM, (2) computer and its systems, and (3) EMIC and EXMOIC. The first network is composed of the PER/LOG, the OPS/INT and the EXMOIC. The second network is composed of the IF/ASM and the EMIC.

Task analytic input data for each of the simulated EMARS' positions were prepared and seven NETMAN parameters were selected for parametric manipulation--four physical and three human parameters. These parameters, along with their variation over model runs in the EMARS simulation, are presented in Table 4-1. The first two physical factors were concerned with the number of messages generated. The number of messages generated, of course, determines the load on the system and the stress on the simulated personnel. The next two physical factors were concerned with the length of the messages entering into and exiting from the system. The human parameters were concerned with the proficiency of the simulated assigned personnel and their level of aspiration.

A total of 22 operational computer runs, a baseline run, and a control run was completed. The operational runs involved a wide spread of variations within each parameter. In each run, only one parameter is varied while all others are held at baseline value. The baseline value of each variable is indicated in a separate column of Table 4-1. These values are essentially "average" input values whose output may be compared with the output produced by the other parametric variations listed.

Table 4-1

Parametric Variation for Each EMARS Run

	Baseline	Run 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Control
Number of messages generated per stimulus message	1	2	3	4																				1
Message frequency per hour																								
Mean	3				10	20	30																	1
S.D.	2				4	8	16																	1
Field message length (No. of characters)																								
Mean	30							10	100	1000														22
S.D.	10							3	30	300														0
Message length to staff (No. of characters)																								
Mean	300										50	100	700											200
S.D.	90										15	30	270											33
Operator speed	1.00													0.7	1.3	1.6								.99
Operator precision	1.0																0.8	0.9	1.1					1.0
Level of aspiration	.95																			.80	.90	.99		.95

The control column represents a previously completed simulation run for the TWSEAS system (Siegel, Leahy, & Wolf, 1979). The run selected is the available prior run which most closely approached the baseline parameters of the present simulations.

Results and Implication of Application for NETMAN

The purpose of the application of NETMAN to EMARS was to allow some insight into the flexibility, transportability, and generality of the NETMAN model. Application of NETMAN to EMARS involved the development of unique task analytic data, special input data, use of the enhanced NETMAN model, and interpretation of the output against the backdrop of the EMARS concept and the TWSEAS system. The preparation of the required task analytic and associated input data was completed without undue difficulty.

The results favored contentions supporting the adaptability of the NETMAN model. The enhanced NETMAN model yielded a set of data which was rational and which was related to the design characteristics of the EMARS system. The model provided insight into system throughput limitations and methods for correcting these limitations. For example, interpretation of the results from the NETMAN application provided insight into the requirement for an additional monitor in the EMARS system.

Comparisons were also possible between the EMARS system and the TWSEAS-type system by virtue of computer runs employing essentially parallel parameters but with different network organizations and task analyses. The results provided direct estimates of the extent of superiority of EMARS over the TWSEAS-type system in terms of such systems effectiveness indices as: overall effectiveness, thoroughness, responsiveness, completeness, and performance degradation as a function of message length and frequency. These metrics are believed to possess important implications for comparative evaluation of alternate systems and for absolute evaluation of an individual system.

Moreover, in all cases, the obtained results seemed reasonable in that they were in a direction which would be anticipated and the model was sensitive to variation in parameters such as message length, message frequency, operator proficiency, operator precision, and operator level of aspiration. Moreover, NETMAN's sensitivity to differences between the simulated systems suggests that NETMAN application may represent a reasonable way to test economically and efficiently the capabilities of such systems while they are in the conceptual stage of development. Moreover, it seems that such evaluations may be completed with some

degree of precision and some assurance that the results will possess meaningful implications for equipment and personnel subsystem design.

The results of the earlier sensitivity and validation tests (Siegel et al., 1979) of NETMAN, along with the current findings, combine to suggest that NETMAN is a useful evaluation tool. Its validity was previously demonstrated and contentions favoring its flexibility and adaptability are supported by the application to the EMARS concept.

CHAPTER 5

SUMMARY, NETMAN'S APPLICABILITY, AND IMPLICATIONS

Following experience with MANMOD, NETMAN was developed specifically to simulate field exercise management systems, and an initial (limited) sensitivity test was completed. Then, the model was the subject of:

(1) panel evaluation
(2) sensitivity testing
(3) validation testing
(4) enhancement
(5) application to the EMARS field exercise management system

The initial test, as well as each of these five tasks, met with general success as reported above:

- the initial sensitivity tests indicated reasonable output, but identified some problem areas (see Chapter 1, Initial NETMAN Sensitivity Tests)

- an independent panel of six experts raised 22 issues for consideration which were prioritized (see Chapter 3, Independent Review Panel)--and held for later consideration

- a sensitivity test consisting of over 60 simulations was conducted. It was concluded that the statistical results were directionally logical, that the model is workable, and that the most sensitive (important) variables are operator speed, operator precision and network configuration (see Chapter 3, Sensitivity Testing Methods and Results)

- model validation against eight TWSEAS criteria showed (see Chapter 3, Integration of Validation Data) that two of the predictors agreed almost exactly with the criterion data, five additional predictors provided predictions which were within one standard deviation of their respective criterion, and one prediction was two standard deviations from the criterion data

- some 27 candidate suggestions for NETMAN enhancement were summarized and prioritized, 17 of which were implemented and documented (see Chapter 3)
- the model was applied to EMARS (see Chapter 4) and it was found that the model is reasonably sensitive, transportable, and adaptable.

However, there are several aspects of the NETMAN simulation which a user should understand:

- NETMAN considers only those key variables shown in Table 2-2. As discussed in Chapter 2, some of these variables are not easily modified. Although the ranges of values are comfortable in terms of systems simulated to date, they may represent restrictions on the model's future applicability.
- NETMAN deals almost exclusively with the message communications, and time aspects of a field exercise management system. For example, environmental factors and equipment design are not directly involved in the simulation.
- Use of NETMAN implies the use of the built-in sequence of message movement. Names of operators and their tasks may be varied, system levels may be deleted, and the computer may be exchanged with an operator (and vice versa). However, the framework is otherwise preconceived.

Within these limitations, it has been found that:

- parameter inputs are readily selected and varied
- the effort of preparation for use of the model and the cost of use is reasonable
- the printed outputs are readily understood and useful
- the user documentation is comprehensible
- the model is adequately sensitive over a wide range of parametric variations
- the test results are reasonable and possess proper directionality

- NETMAN provides data on exercise control system operation which, within reasonable error, predicted actual field exercise control system performance.

With respect to the status of NETMAN, consider Figure 5-1, reproduced from Siegel, Leahy, & Wolf (1979). Figure 5-1 depicts the general sequence of steps in model development, validation, and implementation. NETMAN has progressed from the earliest stages of conceptual design as indicated in Figure 5-1, through the various stages to the point where (subject to its limitations) it is now ready to enter the status of "Decision Aiding."

As such it is available for simulations of field exercise management systems in which:

1. predictions of the effect of operator speed and precision on system performance are of concern
2. message length, message frequency, and queue length plan an important role
3. several levels are involved and each involves a set of message processing tasks
4. the parameters of system size are within the model limits given in Table 2-2.

Recommendations

Given the limitations and restrictions cited above, the NETMAN model is now believed to be adequately tested, evaluated, and documented. The model is believed to possess utility for simulating field exercise management systems. The questions of "why," "how," and "when" to use NETMAN, as summarized in Appendix A, are applicable and pertinent.

- NETMAN can now be used as an evaluative tool, particularly in the comparative evaluation of system alternatives which emphasize the message oriented portions of field exercise systems. Feedback from its use should be monitored in the immediate future by model development as well as user personnel to ensure proper use as well as to evaluate potential improvements in the model as indicated by operational use.

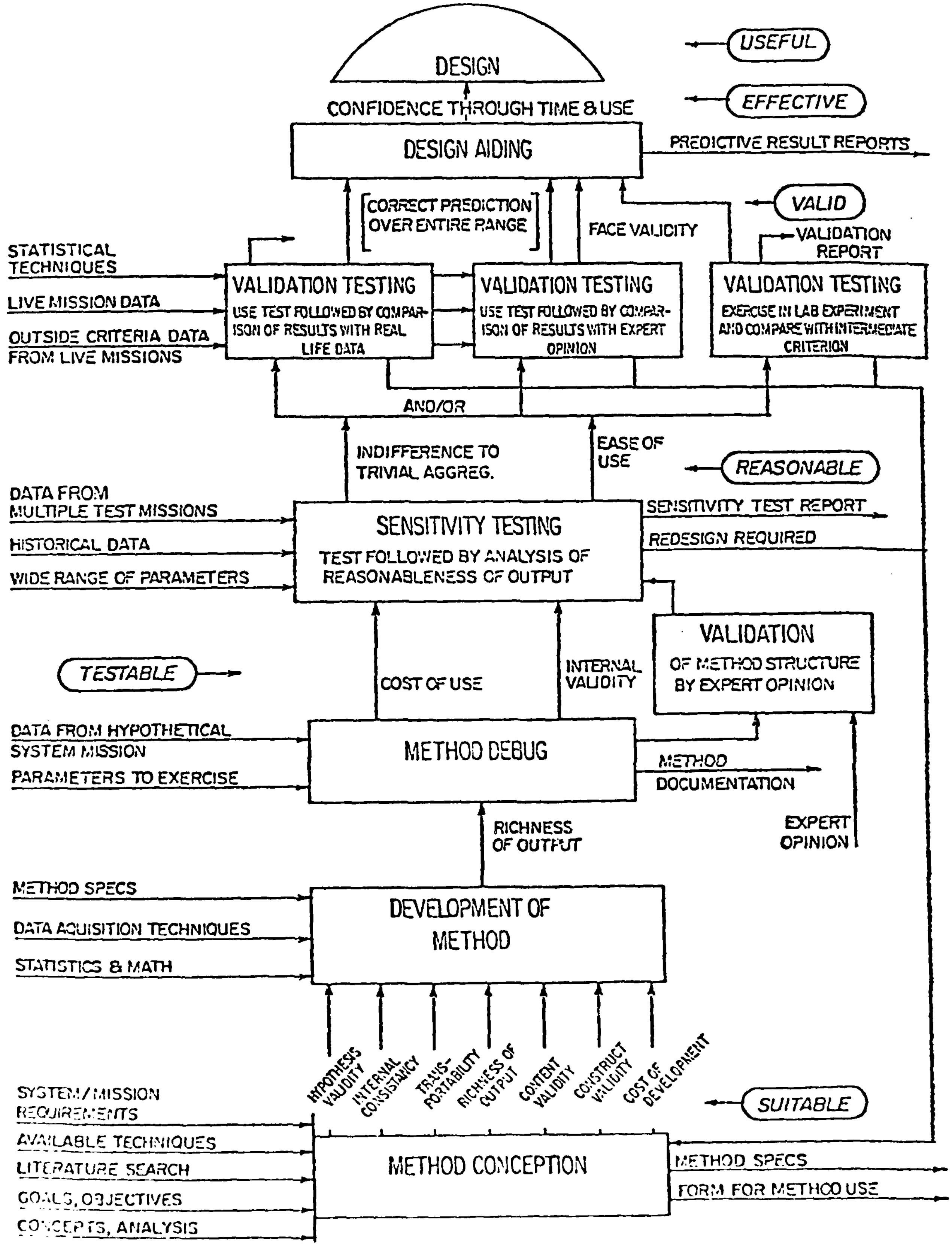


Figure 5-1. Sequence in model development.

- The model, program, and user documentation are now available to appropriate user agencies. A training course for NETMAN users should be considered as a technique for application support.
- NETMAN constitutes a design decision aid which is particularly useful to system designers in gaining insight into the answers to "what if" questions relative to system structure and organization.

Due to the model response to the parametric variations of the sensitivity tests and the agreement between the model and the TWSEAS criterion data, a substantial degree of confidence may be placed in indications derived from the NETMAN computer model. Moreover, the model was implemented at a relatively low cost. Future exercise control system design would benefit from early test through the use of NETMAN. Moreover, the NETMAN model may be used to determine or confirm personnel allocation, effects of personnel proficiency, effects of various operator characteristics, network configuration, and the like in present network oriented exercise control systems.

REFERENCES

Leahy, W.R., Lautman, M.R., Bearde, J.L., & Siegel, A.I. A digital simulation model of message handling to the tactical operations system. III. Further extensions of the model for increased interaction. Research Memorandum 74-11. U.S. Army Research Institute for the Behavioral and Social Sciences, August, 1974.

Leahy, W.R., Siegel, A.I., & Wolf, J.J. A digital simulation model of message handling in the tactical operations system. IV. Model integration with CASE and SAMTOS. Wayne, Pa.: Applied Psychological Services, November, 1975a.

Leahy, W.R., Siegel, A.I., & Wolf, J.J. A digital simulation model of message handling in the tactical operations system. V. User's guide to the integrated MANMOD/CASE/SAMTOS computer simulation. Wayne, Pa.: Applied Psychological Services, November, 1975b.

Leahy, W.R., Siegel, A.I., & Wolf, J.J. Revised User's Guide to the NETMAN Computer Model. Wayne, Pa.: Applied Psychological Services, May, 1980.

Siegel, A.I., Leahy, W.R., & Wolf, J.J. A computer model for simulation of message processing in military exercise control and evaluation systems. ARI Technical Report TR-77-A22. U.S. Army Research Institute for the Behavioral and Social Sciences, October, 1977.

Siegel, A.I., Leahy, W.R., & Wolf, J.J. Application of computer simulation techniques in military exercise control system development. I. NETMAN model sensitivity tests and validation. Wayne, Pa.: Applied Psychological Services, June, 1979.

Siegel, A.I., Madden, E.G., & Wolf, J.J. Application of computer simulation techniques in military exercise control system development: 2. NETMAN transportability and application to an exercise control system. Wayne, Pa.: Applied Psychological Services, December, 1980.

Siegel, A.I., Leahy, W.R., & Wolf, J.J. Stochastic simulation of Intelligence Systems Message Processing Exercises. Wayne, Pa.: Applied Psychological Services, June, 1976.

Siegel, A.I., Webb, P.M., Wolf, J.J., & Wilson, L.B. System conceptualizations for alternative military field exercise management systems. Wayne, Pa.: Applied Psychological Services, June, 1980.

Siegel, A.I., Wolf, J.J., & Leahy, W.R. A digital simulation model of message handling in the tactical operations system. I. The model, its sensitivity, and user's manual. Research Memorandum 73-5. U.S. Army Research Institute for the Behavioral and Social Sciences, November, 1973.

Siegel, A.I., Wolf, J.J., Leahy, W.R., Bearde, J.L., & Baker, J.D. A digital simulation model of message handling in the tactical operations system. II. Extensions of the model for interacting with subject and experimenters. Research Memorandum 73-6. U.S. Army Research Institute for the Behavioral and Social Sciences, December, 1973.

APPENDIX A

Why, How, and When to Apply NETMAN

Why, How, and When to Apply NETMAN

Why

Inherent in any computer simulation concept is the understanding that considerable savings can be achieved by substituting model exercises for actual system test. Such savings, of course, are predicated on a demonstration that adequate agreement can be achieved between a model, such as NETMAN, and actual system operation. Also to the computer model's credit is the aspect of relative time requirea to yield viable results when compared with actual system exercise. The initial data collection and preparation for a model simulation may be extensive but, once completed, the results of parametric variations may be obtained in very short times. It should be possible for a model to yield results in a few hours which would require weeks of time and teams of personnel in the actual exercise situation. Moreover, due to the interactive (remote terminal) capability, the completion of such stochastic simulations is highly convenient. Other advantages of models in general over actual system exercises are:

- exercising a model is less costly
- fewer personnel are involved
- models are independent of uncontrollable conditions
- models do not expose personnel to danger or accidents
- models do not expose equipment to damage
- convenience

Note also that the more complex, costly or large scale the operational system, the more dominant these relative advantages of simulation modeling become.

In addition, the simulation alternative offers the capability to consider and evaluate the impact of new anticipated equipment, different speeds and numbers of communication lines, as yet unauthorized operator sequences/procedures, and system loads.

Proper use of NETMAN will allow the identification of system modifications which afford improvment to the system. By testing the effects of many types of possible system modification, true optimization of the system can be approached.

How

The model can be of use in the area of personnel planning in a number of ways. Primarily the areas of personnel requirements, training, and workload can be assessed. Personnel characteristics such as speed, precision, level of aspiration, and stress threshold are a part of the model's input data. By manipulating the personnel characteristics and examining the resulting system performance, the effects of variations in personnel parameters can be assessed.

The model's output includes such parameters as percentage of time worked and mean stress level during the hour. By evaluating these values the design of work schedules which produce reasonable workloads and acceptable stress levels can be implemented.

NETMAN can be used to investigate the effects of equipment modifications or substitutions on system performance. The effects of equipment are included in the model through the task analysis for each operator. The task analysis includes, among other things, the time required for operating each equipment.

In the evaluation of equipment, however, we note that NETMAN does not actually test equipments--only the equipments' capacity to support the performance requirements is considered by the simulation. The reliability or accuracy of any particular type of equipment must be tested separately and its performance characteristics are incorporated into the task analytic input data. The effect of the equipment on system performance can then be evaluated.

When

There are three major periods in system development in which models such as MANMOD and NETMAN can be used. They can be used as an aid in the initial design of a system, as a testing device in the appraisal of system quality, and as an evaluation tool for system redesign or retrofit. The use of the model in all three cases would be basically the same; however, the degree of accuracy of the input data will increase as more precise use data are available. As the accuracy of the model input data increases, the accuracy of the predictions of the model can be expected to increase proportionally.

APPENDIX B

MANMOD Chronology

MANMOD Model Chronology

An initial report was published (Siegel, Wolf, & Leahy, 1973) which described the MANMOD digital computer model for simulation of message processing tasks performed by field army personnel during a Tactical Operations System (TOS) mission. That report defined variables, described a computational logic flow which integrated the variables into a coherent digital simulation model, and presented the results of initial tests of model sensitivity.

As a result of model utilization and testing, a number of avenues for model improvement became evident:

- extension to allow an experimenter, seated at a CRT display terminal, to initiate, control, and monitor results from simulation runs. The MANMOD model was extended to allow the experimenter to interact with the program and make online changes such as: parameter modification, assignments of personnel and the tasks they perform, and characteristics of messages and message frequency.

- extension to allow one or more subjects, seated at CRT display terminals, to participate in a simulated TOS exercise, by performing specific TOS tasks, selected as not best allocable to digital simulation, while the model simulates the balance of the tasks.

The MANMOD was extended so as to allow "hybrid" simulation in a man-computer interactive manner. In this "hybrid" mode of interactive simulation, a man sitting at a cathode ray tube terminal was assigned the performance of those tasks which are best not treated through digital simulation while the computer simulates the performance of tasks which digital simulation treats well. The simulation is termed "hybrid" since the human can be considered to be an analog device which performs in interaction with the digital logic of a high speed computer. The end result was an interactive simulation which takes advantage of the time compression of the digital computer and allows inclusion of the flexibility of the human components in a man/machine system. The tasks to be performed by the on-line subject are prespecified by the person charged with simulation conduct and can include such tasks as cathode ray tube monitoring, date entry, data comparison, counting, verifying, and decision making. Figure B-1 presents the data flow in this computer, experimenter, subject interactive mode.

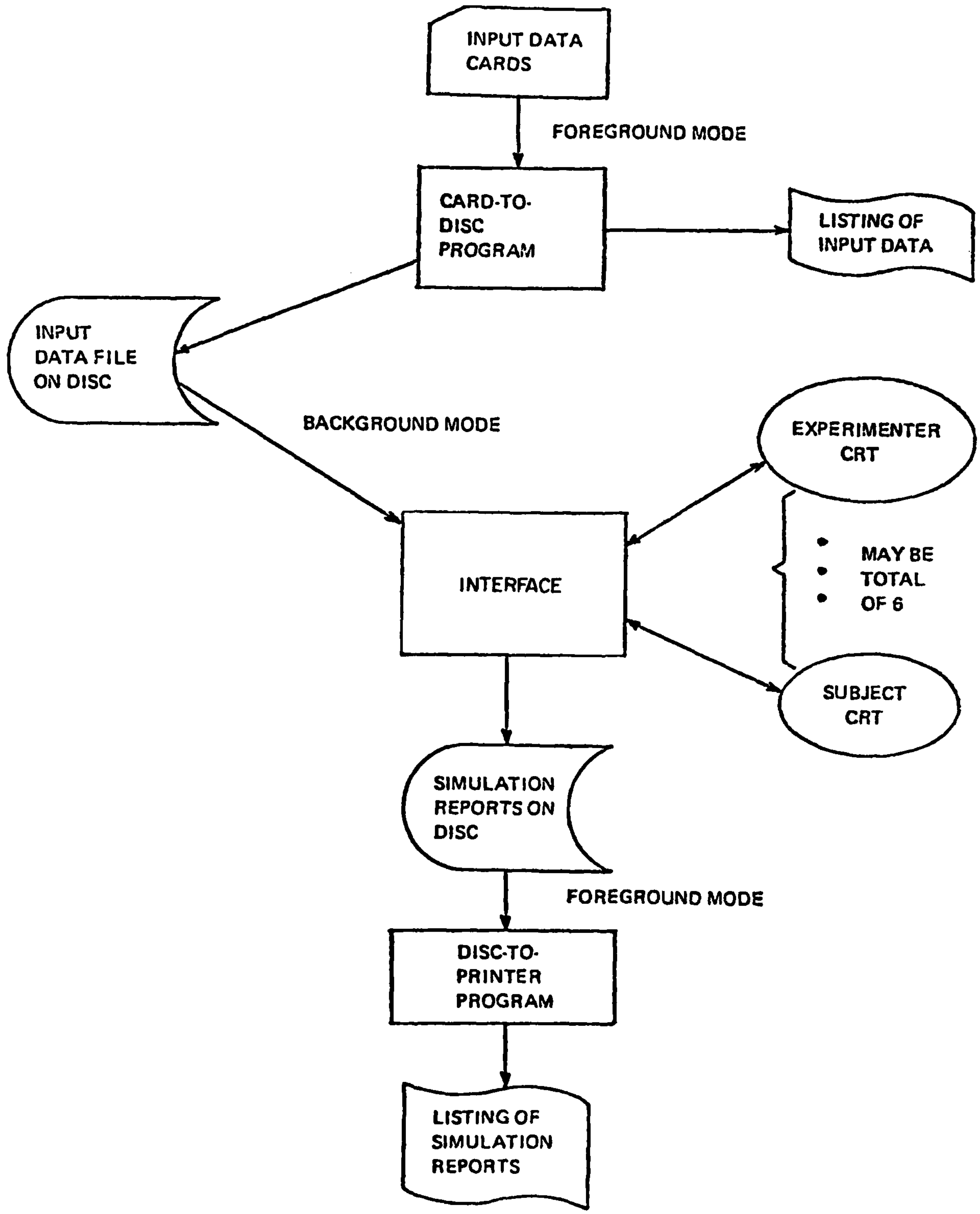


Figure B-1. System flow for the computer-experimenter, subject interactive mode.

- Strengthening of the MANMOD model by incorporating a number of model elaborations including: (1) extension of the number of shifts which can be simulated, (2) revision of the calculation of performance effectiveness, (3) extension to allow the generation of more than one TOS message from a single system input message, (4) correction in the calculation of the number of undetected errors, (5) modification of the calculation of operator stress to allow consideration of the effects of message priority on stress, and (6) improvement in the content and format of the printed output.

In December 1973, a report (Siegel, Wolf, Leahy, Bearde, & Baker, 1973) described the implementation of the features into the previously developed model.

The effects of the modifications on the TOS simulation model's output were tested through a set of sensitivity tests. The results (also reported in Siegel, Wolf, Leahy, Bearde, & Baker, 1973' suggested that the modifications produce reasonable output (i. e., in conformity with logical expectation).

To achieve additional utility, the computer program representing the original model was modified and, as a result two new computer programs were developed. The first program was a revision of the basic model containing improvements only and did not contain interactive features. This was termed the "Strengthened Model," which continued to be called MANMOD. The second was an extended model which incorporated the changes required for the interactive features including both the experimenter and subject interaction, as well as the model improvements included in the "strengthened model" (with the exception of shift extensions, which are impractical for interactive runs). This was called the "Interactive Model."

A second part of the subject interactive mode allowed the computer to call the subject interactive data from disk, average it to provide new human performance data, and then use these data in a new simulation which may be stochastically repeated across many varied iterations. The results from such a stochastic combination of events across many iterations have been found to provide a more consistent, representative, and replicable picture of simulated events.

During 1975, a more useful and more powerful version of the MANMOD was developed for simulating the TOS network. This work included:

- allowing for automatic transfer of data between MANMOD and complementary simulation models called CASE and SAMTOS

- modifying the MANMOD so that it can be run on the U 1108 computer system

- increasing the verisimilitude of the model through incorporation of error message evaluation and interruption features.

In this program the MANMOD was coupled with the CASE and SAMTOS models to allow the strongest features of each to be exercised in an integrated TOS simulation and to strengthen the MANMOD so as to allow greater simulation fidelity. The coupled CASE and MANMOD computer simulation may be performed on the U 1108 system and the results entered directly to SAMTOS. This approach achieved the desired coupling without modifying SAMTOS in any way. Modification of the SAMTOS program was considered to be undesirable because SAMTOS is written in a special language and because certain subroutines in the model are not the sole property of the government. Accordingly, the cost of such a modification would exceed the benefit to be obtained from direct integration.

In the coupled form, the message delay data generated by a revision of CASE are employed as input to the MANMOD. The MANMOD then employs these data within its simulation of the message processing by the system operators. The output of the combined simulation is in a form that it can be entered directly into SAMTOS, which simulates further equipment delay aspects.

The results of the sensitivity tests indicated that the message processing time output is sensitive to variation of the input parameters which directly affect this logic. All tests completed supported the contention that these modifications yield an output in the anticipated direction.

When the MANMOD itself and the coupled models are considered, there seems to be available the ability to simulate and investigate the effects of varying items such as qualitative and quantitative aspects of the manning, message load, equipment characteristics and delay times, message type, and watch length on system effectiveness. Moreover, the output will state not only that a given effectiveness level was or was not achieved but also what contributed to any failures noted. The output detail can provide insights relative to equipment design modification, training requirements and objectives, personnel requirements, and tradeoffs.

APPENDIX C

MANMOD and NETMAN Reports

MANMOD AND NETMAN REPORTS

Item	Title	Authors	Date	No. of Men Simulated	Task Simulated
1	*I. The Model, its Sensitivity and Users Manual (MANMOD)	Arthur I. Siegel J.Jay Wolf Wm.R. Leahy	June 1972	6	Tactical Operations System
2	*II. Extensions of the Model for Interactivity with Subjects and Experimentors (MANMOD)	Arthur I. Siegel J.Jay Wolf Wm.R. Leahy Jon L. Bearde James D. Baker	Dec. 1973	6	Tactical Operations System
3	*III. Further Extensions of the Model for Increased Interaction (MANMOD)	Wm. R. Leahy M.R. Lautman J.L. Bearde Arthur I. Siegel	Aug. 1974	6	Tactical Operations System
4	*IV. Model Integration with CASE and SAMTOS and V. Users	Wm. R. Leahy Arthur I. Siegel J. Jay Wolf	Nov. 1975	6	Tactical Operations System
5	*Guide to the Integrated MANMOD/CASE/SAMTOS Computer Simulation	Wm. R. Leahy Arthur I. Siegel J. Jay Wolf	Nov. 1975	6	Tactical Operations System
6	Stochastic Simulation of Intelligence Systems Message Processing Exercises (NETMAN)	Arthur I. Siegel Wm. R. Leahy J. Jay Wolf	June 1976	57	Tactical Operations System
7	Application of Computer Simulation Techniques in Military Exercise Control System Development I. NETMAN Model Sensitivity Test and Validation	Arthur I. Siegel W. Rick Leahy	June 1979	17-51	Army battalion level field exercise (TWSEAS)

Item	Title	Authors	Date	No. of Men Simulated	Task Simulated
8	Revised Users Guide to the NETMAN Computer Model	W. R. Leahy Arthur I. Siegel J. Jay Wolf	May 1980	NA	NA
9	Systems Conceptualizations for Alternative Military Exercise Control Systems	Arthur I. Siegel Patricia Webb J. Jay Wolf Lawrence Wilson	June 1980	NA	NA